# IMPROVING TRUCK TECHNOLOGY FOR DIFFICULT TERRAIN - Central Tyre Inflation, Twin Power Truck

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## ABSTRACT

Two new concepts which improve the mobility of logging trucks are discussed. A summary of investigations into Central Tyre Inflation by both overseas organisations, and LIRO is presented. The concept of the twin power truck, or power assisted tailer is introduced, and potential benefits discussed. Brief details of the specifications and performance of the twin power truck working in Kaingaroa forest are presented.

## INTRODUCTION

With the harvesting of our forests moving more and more into steep country, as well as giving thought and forward planning to the extraction phase of the operation, we also need to consider the transport operations. There has been a trend in recent years to trucks of higher and higher horsepower, but in steep country, particularly areas with poor soil conditions such as those around the East Coast, horsepower is of no use unless it can be put to the ground.

This paper will discuss two new concepts for improving logging truck traction and mobility. The first of these, Central Tyre Inflation (CTI) is not really a new concept, having been developed during the second world war for military vehicles, but in the last ten years or so, the United States Forest Service (USFS) has conducted extensive trials and actively promoted the CTI concept for the logging truck application. Results and experience from the USFS trials will be discussed, along with the work that LIRO has done in New Zealand with the prototype CTI system built here by National Fluid Power Limited of Auckland.

The other concept is the twin powered truck, or power assisted trailer, working off-highway for Tasman Forestry Ltd in the Central North Island region. This is also not a new idea, but rather a new development of an old concept, and is probably the most successful application of the concept. The benefits of this concept will be briefly discussed, along with the basic specifications of this vehicle and its performance characteristics.

## ACKNOWLEDGEMENTS

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# CENTRAL TYRE INFLATION

## Background

Central tyre inflation systems allow the driver of a vehicle to inflate or deflate the tyres while the vehicle is in motion. This enables the tyre pressures to be matched to the road and operating conditions at any particular time. Decreased tyre pressures on low speed unsealed roads offer a number of benefits, but for high speed highway operation the tyre pressures must be reinflated to the appropriate pressure, requiring the use of a CTI system. The pressure adjustment is usually achieved through an electronic control system with the vehicles existing air compressor supplying the pressure for inflation.

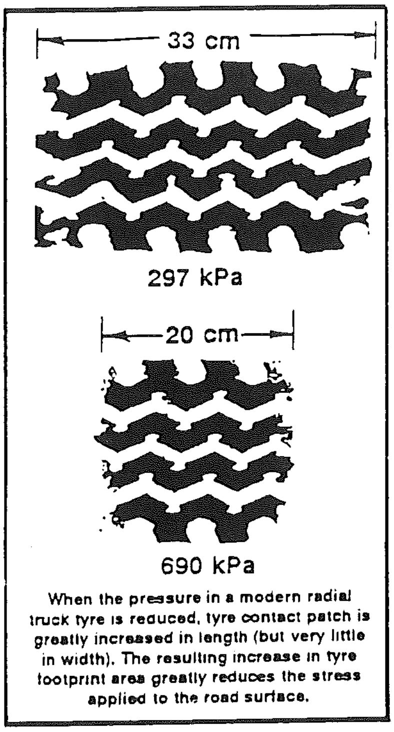


*Figure 1 - Effect of tyre pressure on tyre/road contact area*

Decreasing the tyre pressure causes the contact area of the tyre on the road surface to be increased. Modern radial tyres increase the length of the tyre footprint when pressure is decreased, while the width of the contact area remains approximately constant (Figure 1).

The contact area is determined not only by the tyre pressure, but also by the weight carried by the tyre and to a lesser extent the characteristics of a particular tyre. A measure of these factors is the degree of tyre deflection and it is this that determines the contact area. Tyre deflection is defined as the percentage change in the tyre section height when loaded compared to the unloaded height (Figure 2). A typical relationship between tyre pressure and deflection is shown in figure 3.

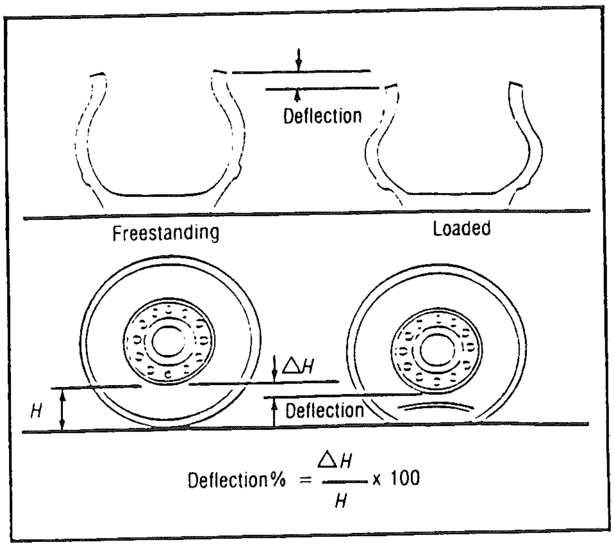


*Figure 2 - Measurement of tyre deflection*

The larger footprint caused by decreased tyre pressure and the resulting greater tyre deflection offers several benefits for low speed ($\leq$50 km/hr) operation on unsealed forest roads; traction on most surfaces is improved, road damage is reduced, ride quality is improved, and truck maintenance may be reduced as less shock is passed through the tyres to the chassis. Offset against these benefits are a slightly increased fuel consumption while operating at low pressures, the initial purchase cost

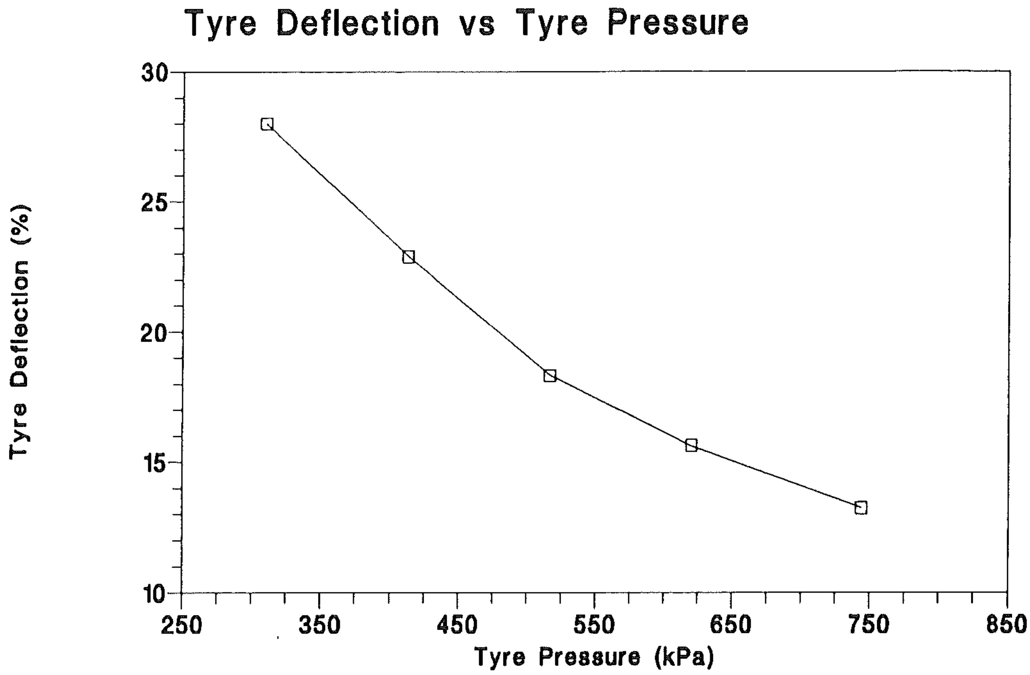


*Figure 3 - Typical relationship between tyre pressure and deflection for the drive tyres of logging truck loaded to 57 tonne gross*

of the CTI system, and the additional maintenance requirements of the CTI system. Other factors that will be of concern to the contractor include the effects on the tyre life and wear rate.

Results from some of the work conducted by the USFS, and the work in New Zealand by LIRO, to evaluate each these benefits is summarised below.

## Traction and Gradeability

Experience with CTI both in the US and in New Zealand indicates that one of the major benefits of CTI is the greater traction available on unsealed roads at lower tyre pressures. The effect of tyre pressure on traction will vary according to the particular materials and construction of gravel roads, and with the soil types on unsurfaced bush tracks and skids, however tests have shown that an increase is achievable on most surfaces.

**Theory**

From a theoretical point of view traction will decrease with decreasing tyre pressure on frictional soils such as sand, and will increase with decreasing tyre pressure (and therefore increasing contact area) on cohesive soils such as clay (Yong et al 1980). Frictional soils increase in strength with increasing confining pressure or contact pressure. These soils are thus able to support greater longitudinal stresses under a high pressure driving tyre than a low pressure tyre if sufficient traction at the tyre-soil interface can be achieved. The strength of cohesive soils is little affected by the contact pressure and so the limiting factor is the traction between the tyre and the soil surface, which is affected by the contact area.

These general trends are however strongly influenced by such things as moisture content, the composition and strength characteristics of the particular soil, and the tread design of the tyre. Normally, larger contact areas through lower tyre pressures will increase traction on both frictional and cohesive soils when they are weak and of low bearing strength (Wronski, 1992). However under drier conditions on frictional soils, because the strength is derived from friction between the individual soil particles which is proportional to applied ground pressure, any increase in traction that arises from increased contact area may be cancelled by the corresponding reduction in ground pressure.

**Overseas Traction Trials**

The USFS have conducted many trials which both qualitatively and quantitatively show the higher traction available off-highway from tyres operated at low pressures.

Drawbar pull tests are the technique commonly used to evaluate vehicle traction and gradeability. This technique uses a load cell connected between the test vehicle and a towed vehicle. The test vehicle pulls the towed vehicle along at a slow steady speed, and the load is gradually increased by applying the brakes of the towed vehicle. The load is increased until 100% slip of the driving tyres on the test vehicle occurs.

Tests were conducted on a three axle logging truck as part of the USFS trials in Auburn , Alabama (Ashmore & Gilliand, 1987). Three different tyre pressures were used, 690 kPa (100 psi), 450 kPa (65 psi) and 205 kPa (30 psi), which gave corresponding tyre deflections of 10%, 20% and 30%.

On a sandy surface a 34% increase in pull was measured at tyre pressures of 450 kPa (65 psi) relative to the pull at tyre pressures of 690 kPa (100 psi). On a saturated clay soil the increase in pull was 17% for the same tyre pressure change. On both the soils no significant increase in pull was observed by decreasing the tyre pressures from 450 kPa (65 psi) to 205 kPa (30 psi).

FERIC in Canada have also recently conducted similar traction tests with a CTI equipped truck on a gravel surface (Bradley, 1991). The tractor unit was loaded with concrete weights to simulate empty running (drive axle loading of 6 tonne). Drawbar pull increases of +10%, +17% and +42% were found at tyre pressures of 414 kPa (60 psi), 310 kPa (45 psi), and 207 kPa (30 psi) relative to the pull at 621 kPa (90 psi). In addition to the increased pull, "bogie hopping" was eliminated at the lower tyre pressures. This would result in less corrugation formation on grades as an added benefit to the traction gains.

**New Zealand Gradeability Tests**

LIRO has also conducted a number of drawbar pull tests on a variety of surfaces to evaluate the traction benefit of low tyre pressures. The results were used to calculate truck gradeability, using a simple method outlined below (Wild, 1990).

$$G_{max} = \frac{DBP_{max}}{GVW} \times 100\%$$

$G_{max}$ = gradeability (maximum % grade)
$DBP_{max}$ = maximum draw bar pull (kg)
GVW = gross vehicle weight (kg)

Tests were conducted on a volcanic ash soil, two different gravel roads, a wet sand track, a surface of bark and mill waste and on a damp sandy clay. For most of the tests, the 8x4 truck fitted with the New Zealand CTI system was used (Jones & Smith, 1991). Two other trucks were used for a set of tests on a river run gravel road, a 6x4 with three axle trailer longs unit, and an 8x4 with four axle trailer shorts unit.

For all tests the trucks were fully loaded with logs. The drawbar pull was measured at a range of tyre pressures, and the tyre deflection was measured for each.

Results

Figure 4 shows the increase in drawbar pull with increasing tyre deflection for the volcanic ash tests. The deflections given are for Bridgestone 11R22.5 L301 tyres. Between 20% and 28% deflection the increase in drawbar pull is only 210 kg, compared to an 1100 kg increase between 15% and 20% deflection.

These results suggest diminishing gains in drawbar pull for tyre deflections greater than about 20%. This agrees with results from the USFS drawbar pull test at Auburn which showed similar trends (Ashmore & Gilliand, 1987). This trend suggests that in practice, a lower limit of 20% deflection will result in the best compromise between increased traction and minimum re-inflation time.

A summary of the NZ tests on the various surfaces is shown in the Tables 1-3. These results show the maximum gradeability obtained, and the corresponding tyre pressure. The gradeability at the standard highway pressures is also given for comparison. The gradeabilities shown here have been adjusted for any existing grade on the test road.

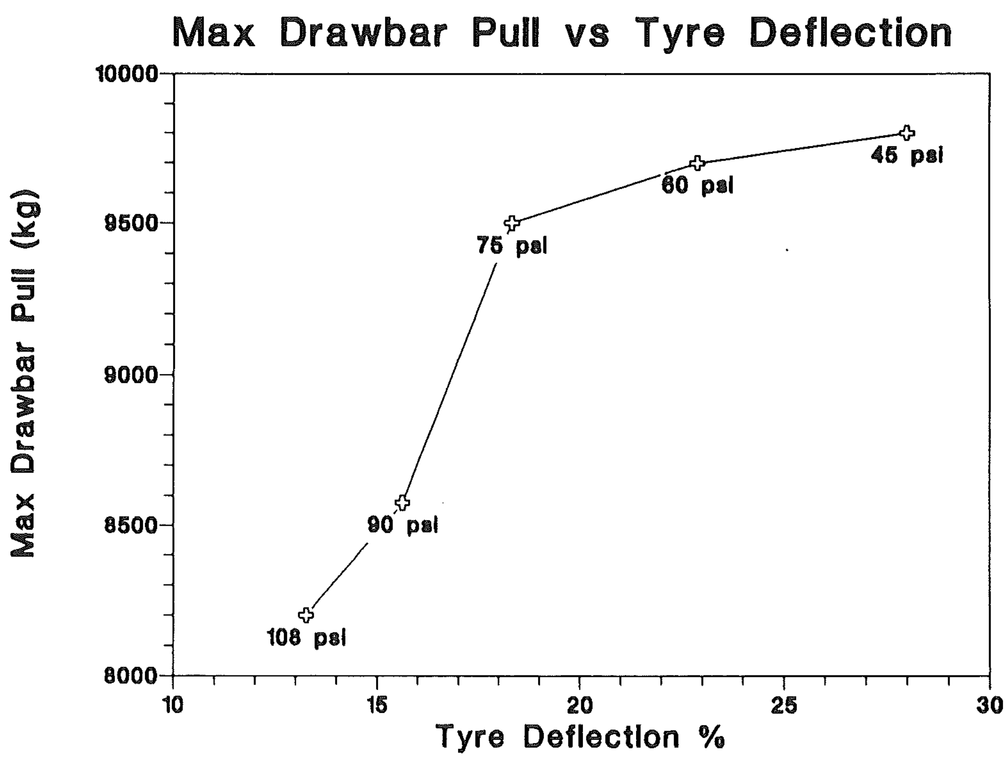


*Figure 4 - Maximum drawbar pull versus tyre deflection (CTI 8x4 on volcanic ash soil)*

| Surface | GVW (kg) | Tyre Pressure kPa (psi) | Tyre Deflection (%) | Maximum Drawbar Pull (kg) | Maximum Gradeability (%) | Gradeability at 690 kPa (%) |
|---|---|---|---|---|---|---|
| Volcanic Soil | 57,200 | 310 (45) | 28.0 | 9870 | 17.1 | 14.6 |
| Sand | 45,180 | 310 (45) | 18.4 | 7800 | 17.3 | 5.5 |
| Bark | 45,180 | 310 (45) | 18.4 | 7200 | 15.9 | 12.7 |
| Gravel (1) | 42,000 | 310 (45) | 17.0 | 5300 | 15.6[1] | 12.0[1] |
| Clay | 45,180 | 690 (100) | 13.5 | 4020 | 8.9[2] | 8.9 |

***Table 1 - Gradeability of the CTI 8x4 truck with two axle pole trailer***

| Surface | GVW (kg) | Tyre Pressure kPa (psi) | Tyre Deflection (%) | Maximum Drawbar Pull (kg) | Maximum Gradeability (%) | Gradeability at 655 kPa (%) |
|---|---|---|---|---|---|---|
| Gravel (2) | 50,560 | 280 (40) | 14.5 | 8720 | 19.2[1] | 17.3[1] |

***Table 2 - Gradeability of 8x4 truck with four axle shorts trailer***

| Surface | GVW (kg) | Tyre Pressure kPa (psi) | Tyre Deflection (%) | Maximum Drawbar Pull (kg) | Maximum Gradeability (%) | Gradeability at 655 kPa (%) |
|---|---|---|---|---|---|---|
| Gravel (2) | 45,360 | 655 (95) | 9.1 | 9497[3] | 22.9[1] | 22.9[1] |

***Table 3 - Gradeability of 6x4 truck with three axle longs trailer***

A large increase in traction was obtained on the wet sand when tyre pressures were lowered. Significant increases were also obtained on gravel and bark. The sandy clay however behaved quite differently and better gradeability was obtained at high tyre pressures than at low. This indicates that the soil was a frictional type and the decrease in soil strength as the contact pressure decreased outweighed the effect of the increase in contact area, as was discussed above (Yong et al, 1980).

Note in the tables that tyre deflection is a function of GVW and even though tyre pressures may be the same, the deflection varies considerably depending on the load carried by the tyres.

The 8x4 truck with four axle trailer on the river run gravel showed an 11% increase in traction, improving gradeability from 17.3% to 19.2% when operating low pressure tyres (Table 2).

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[1] Gradeability has been adjusted for slight grade on the test road

[2] Gradeability was reduced to 5.8% at 310 kPa tyre pressure

[3] Drawbar pull was slightly lower at 40 psi (= 9410 kg)

Although the drawbar pull tests with the 6x4 longs truck did not show any conclusive increases in traction at lower tyre pressures, this truck achieved better gradeability, with a maximum of 22.9%, than the 8x4 truck (Table 3). This truck had a similar weight on the drive axles to the 8x4 truck tested on the same surface, and thus would be expected to have comparable tractive performance. It is not known what caused the better traction of the 6x4 truck, but it is possible that different suspension configuration and different tyres may have contributed. The lack of a measured increase in traction at the lower tyre pressure for this truck is thought to have been caused by changing road conditions over the course of the trial.

These results show that the effect of tyre pressure varies considerably depending on the surface, and traction can also vary significantly between different trucks. On most surfaces however, trucks could be expected to climb grades 2-3% steeper by lowering the tyre pressure to give deflections of around 20%. By utilising CTI to increase truck gradeability, an increase in maximum forest road grades may be possible. This potential increase in grades will allow more flexibility in routing roads in difficult areas.

An increase in road grades of 2% has the potential to save the New Zealand forest industry millions of dollars each year (Wall, 1987). Thus CTI, or any other concept or technology that will allow for greater truck gradeability must be seriously looked at in planning future logging of steep and difficult terrain.

## Fuel Consumption

The rolling resistance of a logging truck's tyres has been identified as the second biggest energy loss (after engine friction) contributing to the fuel consumption (Ljubic, 1982). Tyre inflation pressure has a strong impact on the magnitude of rolling resistances, and so it is important to identify the effect of low tyre pressures using a CTI system in an off-highway situation.

On a sealed road it has long been known that decreasing tyre pressures causes an increase in fuel consumption. However on unsealed roads there may be an optimum pressure to minimise fuel consumption which is below the normal highway tyre pressure (Ljubic, 1985). On a (specific) hard dry gravel road, Ljubic found the optimum pressure for a loaded logging truck was 689 kPa (100 psi), and increased or decreased tyre pressure from this value resulted in increased rolling resistance.

The USFS have monitored the fuel consumption in some of their CTI trials, and have conducted some structured tests in which fuel consumption has been measured. In addition LIRO has conducted two trials to measure the fuel consumption of the CTI equipped truck in NZ.

**Theory**

There are two main factors that contribute to rolling resistance that are affected by varying tyre pressure. These are energy losses in the tyre through tyre deformation, and energy absorbed by road deformation. On softer unsealed roads, while the tyre contribution to rolling resistance will decrease with increasing pressure, the rate of increase of the energy loss by road deformation under the higher contact pressures may outweigh the tyre factor. This would result in higher rolling resistances and fuel consumption at the higher tyre pressure (Yong et al, 1980). Lowering tyre pressures in this situation will then obviously save fuel. In addition to rolling resistances, if the slip between the road and the tyre is reduced at lower tyre pressures for the same input torque (which will depend on the soil type and conditions as discussed in the traction section), this will reduce the interfacial energy losses and further aid fuel consumption and tractive efficiency.

As the road becomes stronger and traction becomes better, the effects of the road deformation and slip will decrease, and the tyre effects will dominate.

From the above discussion, it is apparent that lower tyre pressures will have different effects on the fuel consumption under different conditions.

**US Trials**

In USFS tests at the Nevada Automotive Test Centre (NATC) two identical eighteen wheel logging trucks were operated in adjacent lanes of a specially constructed test track (Nevada Automotive Test Center, 1987). The was track comprised of sections of gravel, thin chip seal and thin asphalt.

Over the 2100 kilometres of loaded operation on the test track, the low tyre pressure truck, with tyre deflections of 20-22%, averaged 1.07 l/km. The high tyre pressure truck, with tyres at 60 kPa (90 psi) giving deflections of 10-12%, averaged 1.06 l/km. In 2100 kilometres of empty running around the course, the low pressure truck averaged 0.75 l/km while the high pressure truck averaged 0.71l/km. This averages out to a 2.6% greater fuel consumption for the low tyre pressure truck.

These tests indicate a very small penalty in fuel consumption when operating low pressure tyres, but as the effect will vary according to the road and operating conditions, it was considered necessary to conduct trials in New Zealand to validate the US results.

**New Zealand Trials**

LIRO has conducted two trials to determine the extent to which operating logging trucks at low tyre pressures through CTI will affect their fuel consumption.

Test One

Tests were conducted around a 4.7 km circuit in Kinleith Forest with the 8x4 CTI truck fully loaded. The road surface of the test circuit was bare pumice soil in dry condition. For these tests the pressure was altered in the driving tyres only, with all other tyres at approximately 690 kPa (100 psi). Three circuits of the road were made at each of five tyre pressures, 725, 621, 518, 414, and 310 kPa (105, 90, 75, 60, and 45 psi). During the tests, the driver maintained a constant speed in sixth gear. For each circuit of the road, the fuel consumption and the time taken were recorded. The fuel consumption was measured using DZL fuel meters.

The results from these tests are shown in Figure 5. The fuel consumption is plotted against the measured tyre deflection. A clear trend of increasing fuel consumption with the increasing tyre deflection can be seen. At 320 kPa (45 psi) tyre pressure, the fuel consumption was 0.93 litres/km, an increase of 5.6% relative to the fuel consumption at a tyre pressure of 725 kPa (105 psi). The mean speed over all the tests was 34.0 km/h, ranging from 33.8 km/h to 34.5 km/h.

Test Two

In addition to these specific fuel consumption tests, the fuel consumption of the CTI truck was measured during a CTI road impact trial in Kinleith Forest. For these tests the pressure was reduced in all

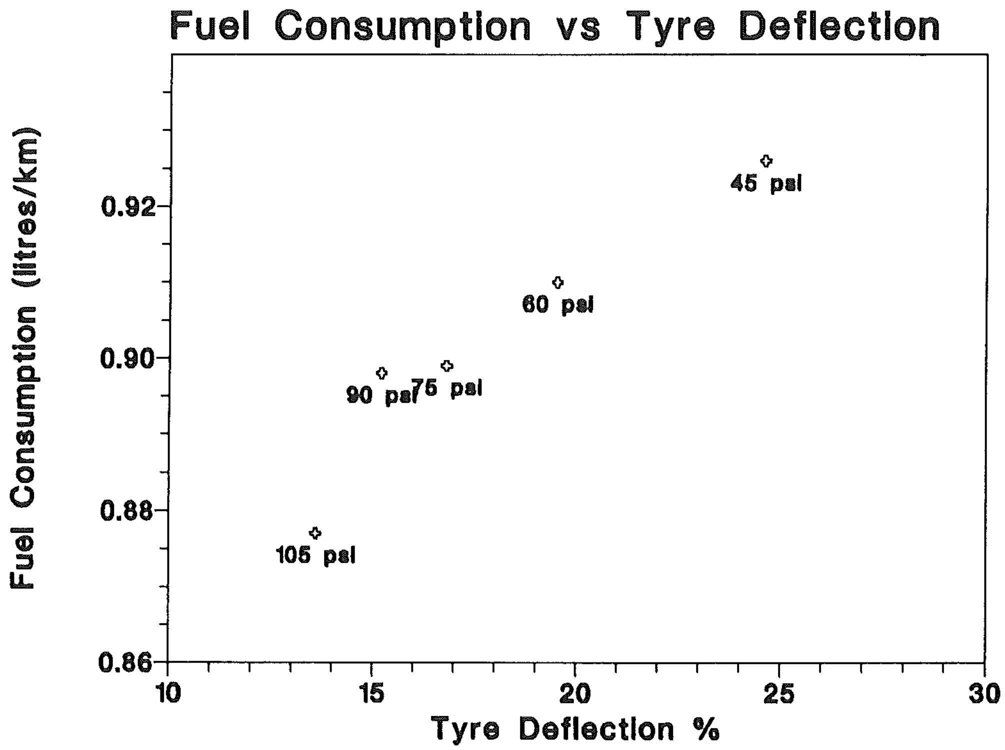


*Figure 5 - Fuel consumption versus tyre deflection*

tyres on the truck. For the high pressure operation the tyre pressures were approximately 720 kPa (104 psi) on the truck and 770 kPa (112 psi) on the trailer, giving tyre deflections of around 10%. For the low pressure operation, the tyres on the steering axles were deflated to 483 kPa (70 psi) and all the other tyres were deflated to 414 kPa (60 psi). These pressures gave tyre deflections of approximately 15%. The gross weight of the truck was 44,000 kg. The truck was driven up and down an 800 metre section of road, and a side road was used to back around at either end. The road used for the test was surfaced with gravel on a clay base and was dry and hard at the time of the test, with average CBR[4] readings of over 30.

For the 53 passes over the road at high pressure the fuel consumption averaged 0.91 litres/km. For 27 low pressure runs, a fuel consumption of 1.01 litres/km was recorded. This represents 11% greater fuel consumption at the lower tyre pressure. It was noted however, that the average time per pass for the low pressure runs was approximately 7% less than for the high pressure tests. This would have partly contributed to the increase in fuel consumption.

<u>Discussion</u>

The tests by FERIC measured an increase in fuel consumption of 8% for a change in 552 kPa (80 psi) at a steady speed of 60 tyre pressures from 690 kPa (100 psi) to km/h on a hard, dry gravel road (Ljubic, 1985). This figure supports the general magnitude of the measured result in the New Zealand tests.

The results from these tests indicate that the fuel consumption penalty of operating

[4] CBR = Californian Bearing Ratio

all tyres at low pressure will be of the order of 10%. As the roads on which the fuel consumption was measured were fairly hard, it would be expected that the penalty would decrease on softer roads where low tyre pressures would most commonly be used.

Given that for most hauls only part of the total distance is off-road, CTI equipped trucks would therefore suffer increased fuel consumption on only part of the journey. Assuming the fuel cost is 14% of the total truck operating and owning costs (Goldsack, 1988), an increase of 10% in fuel consumption over 25% of the haul distance will increase total haul cost by only 0.35%. Although the benefits of low pressure tyres apply to only part of the journey, the CTI system is required to reinflate the tyres to pressures appropriate to the rest of the journey. Thus the fuel consumption penalty is small enough to be ignored, if there is a need for the traction (and road damage) benefits in the particular area.

## Effect on Road Maintenance and Construction - US Trials

The larger footprint of a tyre at low pressure spreads both the vertical and the driving (and braking) load on the road surface over a greater area. In addition to the reduced stress on the road surface as a result of the larger contact area, reduced tyre pressures have been shown to greatly reduce bogie hop and bounce on grades and corners, which will reduce the formation of corrugations. There is also evidence that low pressure tyres can actually heal road damage caused by high pressure tyres.

Thus lower tyre pressures through CTI can lead to lower road maintenance and may permit lower standards of road construction. Both of these factors can produce significant roading cost savings. The roading benefits are the main reason behind the USFS push of CTI, and they have done much work investigating this aspect.

In the USFS tests in Auburn (Ashmore & Gilliand, 1987) a three mile section of good quality unsurfaced road was divided into three sections. Two fully loaded ten wheel logging trucks were driven backwards and forwards along this road, with each road section being subjected to truck operation at one tyre pressure. The tyre pressures were set to give tyre deflections of 10%, 20% and 30%. Each section of the road was subjected to 268 passes loaded and 90 unloaded.

At the end of the test the high pressure section of the road had failed and become impassable. The two lower pressure sections showed very little wear and were in as good condition as when the test had started. At the end of the tests additional passes with tyre pressures of 310 kPa (45 psi) were made over the passable sections of the road damaged by the high pressure tyres. The low pressure tyres produced a pneumatic roller effect that smoothed out the rutted areas and improved the road surface.

There have been other structured trials like the one described above which have shown similar results. Tests have also been run on several actual timber sales in the US. Tyre pressures of 690 kPa (100 psi) down to as low as 172 kPa (25 psi) have been used, with low pressures generally set to give 20% tyre deflection. To varying degrees, all of the trials have shown reductions in road maintenance.

It is clear from these trials that lower road maintenance costs can be attained by operating tyres at lower tyre pressures. The magnitude of the savings will vary considerably according to conditions, and is very hard to judge from the work done overseas. This area requires investigation under typical New Zealand conditions. LIRO has attempted two very short trials to evaluate these roading effects, but it became clear that long term trials under normal operations will be required to produce quantifiable results.

The largest roading benefits of CTI and low tyre pressures will be gained in areas with poor soil conditions where road maintenance is normally high. The benefits will decrease as the terrain and soil conditions improve. With lower tyre pressures placing less demand on the road surface, lower construction standards for forestry roads would be possible.

**Tyre Life and Wear**

A major concern for the truck contractor when considering adopting a CTI system is whether the tyre life will be reduced. USFS tests provide an indication of how tyre life and wear are affected by low pressure operation.

In most of the USFS CTI trials, tyre wear has not been significantly affected by the use of low pressures at low speeds off-highway. In some areas with severe conditions where tyre damage is normally high, tyre life has been reported to increase markedly.

A test by Goodyear on over 400 truck tyres under a variety of conditions is probably the most conclusive to date (Zeally, 1990). CTI and standard trucks were paired and operated together over the test period. Goodyear's tests showed no significant difference in tyre wear between the paired trucks. While no tyres have run full life under low pressures using CTI, to date there have been no problems with recapping CTI tyres. Bandag who have been a major cooperator in the USDA FS program has not detected any problems and some tyres have been recapped two to three times.

In the New Zealand CTI trials, the tyres fitted to the drive axles were regularly operated at low pressures when off highway to gain extra traction. The tyre life that resulted was not significantly different from previous tyres operated at high pressure. The tyres were successfully retreaded at the end of the trials.

These test results in off-highway operation indicate that there is not a great deal of difference in tyre wear or life between tyres run at "normal" highway pressures (approximately 10% deflection) and tyres run at a deflection of 20%. In very rough conditions where a lot of tyre damage is normally experienced, the tyre damage may be reduced with low pressure operation.

**Driver Comfort**

In all the USFS tests, the drivers have reported a smoother ride from the low pressure tyres. Accelerometer measurements in the Nevada tests indicated that the impacts were 2-10 times higher for the high tyre pressures.

**Truck Maintenance**

In the NATC tests (Ashmore & Gilliand, 1987) the maintenance costs for the truck run at highway pressures were eight times higher than the truck running the low tyre pressures. These tests results cannot be taken as conclusive as there is no way of proving that the trucks (or the various individual parts of the trucks) were in an identical condition to start with. It has not been shown that the parts on the high tyre pressure truck failed as a result of greater vibration and shock loading. However it is obvious from the accelerometer measurements taken during these tests that lower tyre pressures greatly reduce the transmitted shocks to the vehicle, which must reduce part failure and truck maintenance in the long term.

Tests have been conducted to investigate the peak torque loading on the drive train of a CTI equipped truck climbing steep adverse grades (Simonson, 1990). The dynamic drive shaft torque was measured at various tyre deflections. The results show that the average torque required to sustain a steady climb is independent of tyre deflection, but with increasing deflection the peak torques produced as the tyre slips and grabs are reduced. This indicates that increasing tyre deflection for truck operation on steep adverse grades will decrease wear of drive train components, relative to the same operation at high tyre pressures.

## Availability and Cost of CTI Systems

In response to the high interest in CTI systems in the United States, there has been substantial development of CTI hardware by a number of companies. Retrofit systems are available which feature up to four pressure settings, with each setting controlling up to three axle groups at different pressures. Over-speed protection, which automatically inflates the tyres if a preset speed is exceeded for a certain tyre pressure, is standard, as is leak and puncture detection and alarm. The main suppliers have been developing systems for up to ten years for the military market, and so have an established track record. Eaton Corporation is now also producing CTI systems that have internal axle seals for the driving axles, doing away with the need for external hoses.

In addition to the US suppliers, the New Zealand company who developed the system used in LIRO trials has been working on an updated system which will incorporate many of the features of the US systems.

The cost of a fitted system, including a large compressor and air reservoir tanks is estimated at $25,000 for a seven axle truck. Details of the suppliers is available from LIRO on request.

## Future of CTI in New Zealand

At this stage the effects on traction, fuel consumption and tyre life, of lowered tyre pressures through CTI, are well established and understood. The area that needs further careful investigation in New Zealand are the effects on road maintenance and construction. A quantifiable measure of the roading effects is required, in order to carry out a cost - benefit analysis and thus determine the economic feasibility of CTI. The owning and operating costs of a CTI system also needs investigation. A comprehensive study of these factors is required before any decisions can be made as to adoption of the technology.

The areas where CTI and low tyre pressures are most likely to provide benefits are in difficult terrain areas, where roading problems due to the steepness and or poor soil conditions are prevalent. For this reason future work with CTI should be in these regions. Future work should use the best available CTI hardware to remove system development problems from studies and to establish the commercial viability of the available hardware. All tyres on the truck and trailer should be controlled by the CTI system, and work should be done comparing effects of all tyres at low pressures relative to just deflating the driving tyres. It may be that road damage is decreased only slightly by deflating nondriving tyres, and a CTI system for drive tyres only will greatly reduce the cost, complexity and pressure adjustment times of the system.

A further factor in the feasibility of CTI is in the length of unsealed travel. Short off-highway distances of less than around 15 minutes travel may make CTI impractical due to the time required for inflation and deflation.

LIRO sees CTI technology as having excellent potential in the right place, and is keen to do further research on it. This is dependent on the backing of forestry companies and truck contractors who are willing to try new ideas to reduce overall transport costs.

## Who Should Pay for the CTI System?

If a careful analysis of the benefits and costs of CTI in a certain area show that an application of the technology is worthwhile, then the question arises as to who should pay for the purchase, fitting and upkeep of the CTI system.

Most of the benefits of CTI technology are likely to be gained by the forest company. The reduced roading costs are likely to be the largest benefit, followed by a more consistent and reliable wood flow due to the increased mobility of the logging trucks.

The truck operator also gains some benefits from the increased traction, which may result in increased productivity. However the fuel consumption may rise by 5 - 10% for the low pressure portion of the trip. If steeper grades are taken advantage of by the forest company, a increase in wear of drive train components may occur depending on the conditions.

With the balance of the advantages being reaped by the forest company, it is reasonable that they bear the majority of the cost. This may be done by the trucker purchasing the CTI system and having the cost compensated in the cartage rate over the duration of the contract. The cost of maintenance and upkeep of the CTI system would logically be the truck contractors responsibility, and may be a fair cost to the contractor if conditions and experience indicate that he will accrue some benefits from CTI. Although there is little data recorded on maintenance requirements, a reasonable estimate would be around $1500 per year. Other factors such as the proportion of off-highway low pressure operation, which will determine the increase in fuel consumption, and any increase in average grade to take advantage of the greater traction, must also be taken into account in the cartage rates.

## Conclusions - CTI

The extensive work carried out by the USFS, combined with the trials conducted in New Zealand by LIRO, prove conclusively that there are benefits in operating low tyre pressures through a CTI system.

The traction is significantly improved on most surfaces at low tyre pressures. The damage to unsealed and unsurfaced roads is also decreased by lower tyre pressures, although it is harder to quantify. These are the two main benefits.

Other secondary benefits that have been shown to result from lower tyre pressures when off highway are a better ride and less impact transfer to the chassis. Truck maintenance benefits may also result, particularly in the drive train when operating in adverse terrain.

Fuel consumption may increase by up to

10% over the part of the trip at low tyre pressures. Tyre life and wear appears to be unaffected by low tyre pressure operation at low speeds.

The magnitude of the benefits that CTI and low tyre pressures can provide has been shown to be variable dependent on the conditions. Both traction and reduced road damage benefits will be greatest in areas with soils of poor bearing strength, particularly in steeper areas. It is under these conditions that CTI systems will be advantageous, especially if good rock is expensive. The cost of a CTI system will not be justified in easier areas where the full benefits will not be attained.

Further work is required into the application and benefits of CTI, particularly the roading effects and evaluation of available hardware, before commercial feasibility of the concept can be determined.

## TWIN POWER TRUCK

In an effort to improve the efficiency of power transmission through the wheels various devices to increase traction have been tried over the years. Probably the most effective method is to increase the number of driven wheels, and the various forms of power assisted trailers are one way of achieving this. The total tractive ability of a vehicle combination can be increased by up to 100% by the use of power assisted trailers, accompanied by increased startability, greater payloads and possibly higher travel speeds, depending on the power assist design used. In addition to the improved vehicle performance, power assisted trailers will also impact on the road design and construction, allowing greater grades and possibly lower construction standards.

### History

Since early this century various methods have been tried to power the wheels of trailers (Stjernberg, 1981). Early attempts with agricultural tractors used various electrical, mechanical and friction drive systems where the power was supplied by the tractor engine.

Later, in the 1950's, powered converter dollies were introduced in the US. These were a self contained power unit and drive train, and were used between the trailers in a double trailer combination. These units reportedly had reasonable success.

A similar power dolly was built for logging operations in Canada in 1970. A 138 kW engine drove through an Allison automatic transmission. An over-running clutch on the drive shaft allowed the dolly engine to idle when the power assist was not required. A manual gearbox was used on the tractor unit and the incompatibility of the drive trains caused the trials to be "not entirely successful", although the potential of the concept was recognised.

Around the same time in Sweden, a power dolly was developed which used an identical drive train to the tractor, and the unit was reported to have performed well.

Power assist systems mounted on trailers can be divided into two types; a hydrostatic drive system which provides extra tractive ability when required at low speed only, and a mechanical system which consists of components similar to the truck, and therefore can operate continuously at any speed.

Both of these systems have been used successfully, with hydrostatic drives still being used in various areas. A mechanical power assisted semitrailer was built for logging in Canada during the 1970's, which used identical Detroit 6V71 engines and Allison HT750 transmissions in the truck and trailer. This unit performed satisfactorily for two years, and had a top speed of 65 km/h.

## The New Zealand Twin Power

The power assisted trailer, or twin power truck operating off-highway for Tasman Forestry Limited (TFL) in Kaingaroa forest is a further development along the lines of these earlier systems built in Canada. The unit was built in Canada by ex-patriate New Zealanders Nolan Magee and his son Lance, operating as Marathon Truck and Trailer Limited. The twin power truck started working for TFL in 1990.

**Specifications**

The truck is a Pacific P510 powered by a Caterpillar 3406B ATAAC rated at 425 hp. Drive is through a heavy duty Allison CLBT6062 automatic transmission and two speed Eaton diffs. The semitrailer is custom built to house the second engine, which is another Caterpillar 3406, but rated slightly higher at around 475 hp. The engine is completely enclosed in the trailer, with cooling and intake air drawn from ahead of the fifth wheel and through the gooseneck of the trailer. The transmission and the drive axles in the trailer are the same as the truck. The truck cannot be operated on just the front engine without disconnecting the driveshaft of the rear engine.

The six speed transmissions are individually computer controlled, with communication between them.

A total of around 2300 hp in retardation is available, adding safety to the combination. Each engine is fitted with a Jacobs brake, and along with a Brakesaver on the truck engine and a retarder built into each transmission, the unit has an impressive amount of "whoa" to add to the "go".

Tare weight of the truck and powered semitrailer is around 27 tonne, and the second trailer weighs in at approximately 10.5 giving a total tare for a double unit of 38 tonne.

**Performance**

Although the main philosophy behind the design of the truck was superior traction, greater payloads and quicker travel times, compared the standard off-highway doubles, are achievable.

Productivity

The rig normally operates as a double unit towing a four axle off highway trailer, with a gross weight of 120-150 tonne. It has also been trialled as a single unit and a treble unit, and has been built to cart at up to 200 tonne gross.

As a double unit payloads range from 80 to 110 tonne, limited to the low end by the lifting capacity of the unloading equipment at the Lakeside mill. The travel time for the twin power is well down on that of the conventional double units operating in Kaingaroa, with over one hour pruned off a typical round trip (average 180km) to the Lakeside mill.

Data collected on trip times and payloads over a one month period are summarised below in Table 1. Average data for the TFL off-highway Pacifics is presented for comparison. The Pacific data has been calculated by a TFL trip time model, for the same routes as the twin power.

It can be seen that the average payload recorded for the twin power in all configurations, is higher than the average used by TFL for the conventional Pacifics. The mean trip times, (including loading,

| | Twin Power | | | Off-Highway Pacific | | |
|---|---|---|---|---|---|---|
| | Single | Double | Treble | Single | Double | Treble |
| Mean Payload (tonnes) | 41.8 | 88.3 | 119.7 | 35 | 66 | 99 |
| Mean Trip Time (hrs) | 3.29 | 3.15 | 4.63 | 3.69 | 3.88 | 5.61 |
| Mean Trip Distance (kms) | 72 | 57 | 77 | 72 | 57 | 77 |
| Mean Productivity (tonnes-km/hr) | 915 | 1598 | 1984 | 683 | 970 | 1359 |

*Table 1. Comparison of Productivity of Twin Power and Conventional Doubles*

unloading, and round trip travel time, but no delays for the Pacific), are significantly lower for the twin power. Combine the higher average speed and the higher payloads of the twin power, and it is 34%, 65% and 46% more productive than the conventional units. The productivity for the twin power treble would be expected to be up to 8% higher if averaged over a larger number of loads, due to excessively large unloading times in the trips recorded.

Gradeability

The gradeability of any truck is largely determined by the percentage of weight carried by the driving axles. Knowing an approximate weight distribution, a calculation can be made of traction limited gradeability (Wild, 1990). The twin power as a empty double carries approximately 55% of its weight on the driven axles, which would give it a gradeability of approximately 20% on a loose gravel surface with a relatively low coefficient of traction of 0.4. Loaded with a 100 tonne payload, the weight on the driven axles drops to around 50%, giving a traction limited gradeability of approximately 19%, with sufficient power to maintain 7.5 km/h.

For a conventional double (Mack double) similar theoretical predictions give for an empty unit, 30-35% weight on the drive axles resulting in approximately 10-12% gradeability. Loaded with a total payload of 90 tonnes the weight on the drive bogie drops to around 26% which would give a gradeability of around 8.7%. The power available (500 hp) would give a maximum speed of the loaded unit up the traction limited grade of approximately 9.7 km/h.

These results are summarised in table 2. From the above discussion it can be seen that the twin power truck has approximately twice the traction and gradeability of a conventional double unit, both empty and loaded. It also has a power to weight ratio that allows it to maintain almost the same speed as the single engined trucks, while negotiating twice the grade.

In practice the twin power truck has hauled payloads of 85 tonnes up a 20% winding grade with ease. Single unit highway trucks were unable to negotiate the grade unassisted, and were causing damage the road such that their use was ceased.

The excellent traction and gradeability of the twin power truck may allow access roads to be built to greater grades and may also allow lesser surfacing requirements. This has the potential for large savings in roading in difficult terrain areas.

Manoeuvrability

The twin power truck as a double will

| | Twin Power Truck - Double Unit | | Conventional Double Unit | |
|---|---|---|---|---|
| | Empty | Loaded | Empty | Loaded |
| GVW (tonnes) | 38 | 138 | 22.6 | 112.6 |
| Weight on driven axles (tonnes) | 21.1 | 71.1 | 7.6 | 30.1 |
| Gradeability % | 20.2 | 18.6 | 11.5 | 8.7 |
| Speed up grade (km/h) | 25.3 | 7.5 | 38.3 | 9.7 |

*Table 2. Comparison of Theoretical Gradeability for Twin Power and Conventional Double*

have a similar manoeuvrability to the standard off-highway doubles, as the dimensions are similar. As such the offtracking and turning circle will be larger than for a highway dimensioned truck. This will limit the application of the twin power truck in its current dimensions in difficult terrain where tight turns may be a necessity.

**Applicability of the Concept**

The present twin power truck working in Kaingaroa has shown that the concept of twin engines is a feasible proposition. In its current guise, the unit is a dedicated off-highway truck, which will limit the areas in New Zealand where it could be used. As it is now, the truck is being used mainly for its productivity rather than for its greater traction capabilities, and in this role it seems to work well.

As an off-highway truck, the twin power concept could be used to two stage wood in areas where conventional trucks cannot access because of traction limitations. With twin power trucks only carting out of an area the road grades could be increased which would reduce the roading costs.

The concept can of course be down sized to highway dimensions using smaller engines, with a total of 373-448 kW (500-600 hp). As a highway truck it will suffer a tare weight disadvantage of around three tonnes. The resulting smaller payload would make such a rig less economical unless advantage can be made of its greater capabilities off-highway, by making savings in the construction of roads, and by using it in areas where a standard highway truck simply cannot go. It is not known what view the MOT would take of this concept, and difficulty in getting approval could be anticipated.

An alternative to the twin power approach to power assisted trailers is the hydrostatic drive option. This would be better suited to general purpose highway trucks. The hydrostatic drive approach uses low speed high torque wheel motors to drive the trailer wheels. The drive is engaged to add traction on traction limited grades at low speed only, and is free-wheeled for normal operation. This system adds substantially less to the tare weight of the rig than a two engine approach.

**Conclusions - Twin Power Truck**

The mechanical feasibility of the twin power truck concept has been proven by Marathon Truck and Trailer Ltd. The concept of the existing truck greatly increases traction, and productivity is also increased. This concept may be scaled down or adapted to suit operation in other areas.

Power assisted trailers will reduce the

difficulty of carting in demanding terrain, and may allow for reduced roading costs. However, a detailed analysis would be required to establish the economic feasibility of the concept in any particular area.

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